RS&H **Memorandum**

TO: North Florida TPO

FROM: RS&H Team

DATE: July 5, 2019

RE: Task 2: ***Develop Strategies***
Resiliency & Vulnerability Assessment Phase II

1 INTRODUCTION

1.1 OBJECTIVE

This report is part of a series of deliverables associated with Phase II of the *Resiliency & Vulnerability Assessment,* as a precursor evaluation to update of the North Florida TPO 2045 Long-Range Transportation Plan. *Resilient infrastructure* has been adopted as a Long-Range Transportation Plan objective for the region.

This study summarizes available and appropriate strategies to address transportation assets and system vulnerabilities related with future coastal flooding, riverine flooding and stormwater overflow.

RESILIENCE

The ability to prepare and plan for, absorb, respond, recover from, and more successfully adapt to adverse events… enhanced resilience allows better anticipation of disasters and better planning to reduce disaster losses — rather than waiting for an event to occur and paying for it afterward.

-National Research Council, 2012

A toolbox of potential strategies to improve transportation resilience and planning-level opinion of probable costs are provided on a per unit or per mile basis.

1.2 STUDY AREA

The area of study comprises the North Florida TPO service boundary. This region includes the Florida counties of Clay, Duval, Nassau and St. Johns.

The area is characterized by proximity to the Atlantic Ocean and the St. Johns River, one of Florida's primary commercial and recreational waterway. The study area encompasses over

3,000 square miles and a population of nearly 1.4 million. The area is served my multiple interstates (I-95, I-10, I-295), expressways (First Coast Expressway), and numerous national, state and local roads.

Riverine Area

Roads and bridges over or near rivers and tributaries are subject to sea level rise and nuissance flooding.

Coastal Areas

Transportation infrastructure can be impacted by nuissance flooding and impaired due to storm surge.

Stormwater

Normal and abnormal precipitation can pose a danger to infrastructure and commuters alike.

2 Regional Characteristics & Stressors

2.1 Regional Transportation Assets

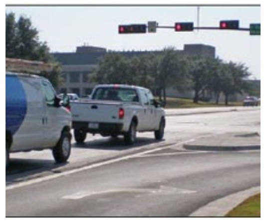
Standard federal functional classification organizes North Florida's transportation network based on the role it plays within the region. Factors such as traffic volumes and strategic use help determine eligibility for federal aid programs. As different purposes may require different resiliency strategies, this report evaluates resiliency best practices in the following assets:

- Interstates & Freeways – All highway segments as part of the Interstate-System and uninterrupted flow facilities such as Freeways and Expressways.
- Arterials – All other principal arterials and minor arterials; excluding interstates.
- Urban Local and Collector Roads – All urban collectors and local roads.
- Rural Local and Collector Roads – All rural collectors and local roads.
- ITS/ Smart Region Systems – The critical technology and applications, including data, used to operate the infrastructure and enable reliable network communication.

Interstates & Freeways

- Example: I-295 (Duval County)
- **High-capacity** and high-speed facilities
- **Freight** critical

Arterials



- Example: Blanding Blvd (Clay County)
- High-capacity with **traffic signals**
- Evacuation route
- Serves **transit**, **bike/ped users**

Urban Roads & Facilities

- Example: Riberia St. (St Johns County)
- Lower-speed road serving **local users**
- Can include on-street parking

Local Roads & Facilities

- Example: Owens Farm Road (Nassau County)
- **Low-volume traffic**
- May link **to freight nodes**
- Little non-vehicular

2.2 Environmental Considerations

2.2.1 Coastal Flooding

Sea Level Rise

Research by the US Army Corps of Engineers and climate science experts predict continued or accelerated climate change which would cause a rise in global mean sea level. The resulting Sea Level Rise (SLR) will likely impact coastal roadway projects and system performance in the North Florida region.

Local areas of concern include coastline roads such as SRA1A and facilities along the St. Johns River, the Intracoastal Waterway and the Atlantic Ocean specifically.

Nuisance Flooding

Nuisance flooding—also called shallow coastal flooding, sunny-day flooding and tidal flooding—causes seawater to spill onto land at high tide, inundating low-lying areas. This type of flooding can occur even on sunny days and is expected to become more common in coastal areas as sea levels rise. Although often associated with “king tide” events that occur in the Fall of the year, nuisance flooding can occur whenever there is a sufficiently high tide.

Storm Surge

Storm surge is the seawater level rise during a storm, measured as the height of the water above the normal tide. The surge is caused primarily by a storm’s winds pushing water onshore. The storm surge at any given location depends on the orientation of the coastline with the storm track; the intensity, size and speed of the storm; and the local submarine topography.

The North Florida transportation network, due to its proximity to the ocean and relatively flat terrain, is susceptible to these impacts as storms and hurricanes approach the region. For example, the shutdown of the Browns Creek Bridge on Heckscher Drive for emergency repairs associated with Hurricane Irma storm surge required some users to a 50 mile detour through Nassau County, according to the Florida Department of Transportation.

2.2.2 Riverine

Riverine Flooding

Riverine flooding can result whenever the volume of water from a nearby river overcomes the capacity of the natural and built drainage systems. It is caused by extreme precipitation events which exceed the capacity of rivers and streams to carry away the excess runoff. Even precipitation that falls outside our area can contribute to flooding as the St. Johns River carries upstream runoff through north Florida to the coast. Riverine flooding can be widespread as the overflow affects smaller rivers downstream, inundating nearby low-lying areas and roadways.

Flood severity depends on the amount of precipitation received and how quickly it accumulates. Previously saturated soils can contribute to more severe flooding as they do not drain as quickly. Downtown Jacksonville (Riverside) is an example of riverine flooding can have long-lasting effects since it may take days or weeks for rivers to subside. In tidal streams, this can result in recurring flooding events at high tide.

2.2.3 Stormwater

Inland Flooding

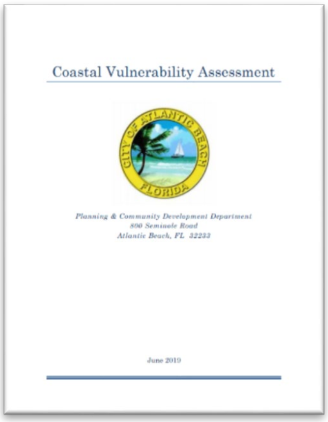
Inland flooding occurs whenever the volume of water on land overcomes the capacity of the natural and built drainage systems to carry it away. This type of flooding can occur independent of an overflowing water body, and even in areas located far from the water. In urban areas with a high proportion of impervious surfaces, extreme precipitation events can trigger flooding when the design capacity of stormwater systems is exceeded. The overflowing stormwater can inundate streets and buildings, especially in low-lying areas. If stormwater systems are poorly maintained or blocked with debris, inland flooding can be exacerbated.

2.3 Past Studies & Reports

North Florida TPO

Path Forward 2045 - Transportation Infrastructure Flooding Evaluation – As part of the LRTP update, the North Florida TPO requested a study that looked at the resiliency and vulnerability of the North Florida transportation network. The 2018 study considered three flood-related scenarios (sea level rise, inland flooding and storm surge).

County/City Reports



City of Atlantic Beach, Florida

The City of Atlantic Beach, as part of a Resilience Planning grant, is undergoing a four-phase assessment and developing goals and policies related to coastal resilience. The study included *Sea Level Rise Projection Review*, *Coastal Flooding Assessment* and *Vulnerability assessment*. Based on their 2044 and 2069 projections, many critical facilities would be located within the projected flood zones. The city is currently reviewing their adaptation planning process to determine what actions if any should be taken.

Clay County

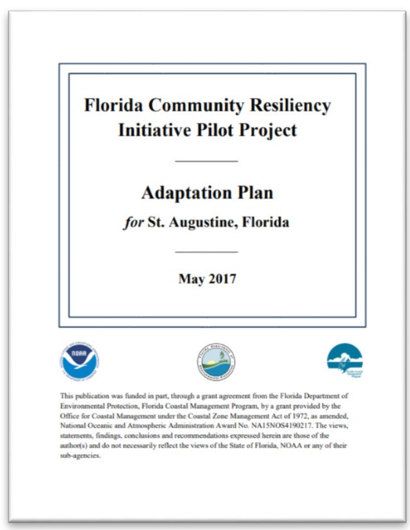
In 2015, Clay County along with municipal governments created a Local Mitigation Strategy (LMS). This list identifies 20-30 community mitigation projects on its Prioritized Project list to reduce vulnerability of natural and man-made hazards. Projects typically involve a combination of funding.

Duval County/City of Jacksonville

In 2019, the City of Jacksonville established the *Storm Resiliency and Infrastructure Development Review Committee* (SRAIDRC) to evaluate existing guidelines and potential future policies, including drainage design criteria, raising the minimum floor height to two feet, and amending the flood plain management ordinance. Distributed documents can be found online at http://www.coj.net/sraidrc.

Nassau County

Nassau County recently received a state grant to complete a *Vulnerability Assessment* for parts of the County, including Amelia Island. The project will look at stressors such as flooding and sea level rise. The two areas under study for first phase are east of I-95 on the mainland and west of I-95 south and west of A1A/SR 200/301.



City of Fernandina Beach

The City of Fernandina Beach hosted a *Waterfront Resiliency Workshop* in mid-2019. The city expects to develop a Waterfront Resiliency Master Plan to effectively plan future infrastructure investments and presentation.

City of St. Augustine

The city is part of the Community Resiliency Initiative Pilot Project funded in part through a grant agreement from the Florida Department of Environmental Protection, Florida Coastal Management Program. An initial study in 2016, *Coastal Vulnerability Assessment: City of St. Augustine, Florida*, reviewed three types of coastal flooding and assessed the vulnerability of the city to existing flood conditions as well as an incremental approach. Among other findings, the report indicates that nuisance flooding could affect up to 30 percent of the road network with 1.5 foot increase of sea level rise.

The city hosted a *Resiliency Workshop* in 2018 to provide a forum to discuss local strategies and the desirable outcomes of a Resiliency Plan.

3 Strategies

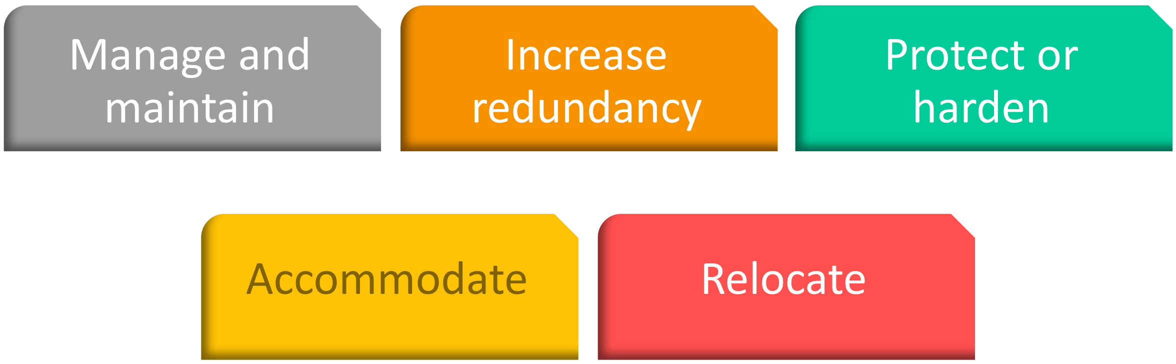
Adaptation strategies are planning measures designed to address vulnerabilities by increasing resilience to climate change. If successfully planned and implemented, they can potentially reduce future economic, environmental and social costs associated with climate impacts. However, it can be challenging to develop successful strategies because of uncertainties regarding future climate impacts and how they may affect transportation infrastructure, usage patterns and demand.

Successful adaptation strategies exhibit a few key characteristics. To deal with the uncertainty surrounding climate science, they should be flexible enough to apply even if conditions change from those anticipated in the original planning process. They should be specifically tailored to the unique conditions of the region in which they are to be implemented. They should be integrative, considering the complex interaction of climate change impacts on human systems. These may include potential secondary impacts such as economic disruption, migration, or changes to travel patterns. Finally, they should be cost-effective and seek to have multiple benefits when possible.

To ensure strategies are flexible enough to respond to changing conditions and climate projections, consider developing thresholds for climate impacts. When these thresholds are reached, specific actions will be taken to ensure resilience. For instance, a flood barrier could be constructed once sea level rise has reached a specified elevation. Strategies will vary depending on the type of climate impact and specific vulnerability they are designed to address. Some strategies are designed to address vulnerabilities to temporary but acute events such as storm surge. Others may address more long term but permanent impacts such as flooding associated with sea level rise. In addition, some may be policy-based while others may involve renovating or constructing infrastructure. Strategies can be included in project planning and design phases for new infrastructure or in retrofitting or maintaining existing infrastructure.

3.1 Types of Adaptation Strategies

Adaptation strategies for transportation infrastructure typically seek to increase resilience in one of the following ways. They may include[1]



Strategies that manage and maintain either manage acute climate impacts through pre-planning or seek to ensure existing infrastructure is prepared through maintenance for optimal performance. Those that increase redundancy improve the resiliency of the transportation system by providing alternative routes or duplicative infrastructure that lessens the chance of failure. Strategies that protect or harden infrastructure seek to make it impervious to climate impacts by providing physical barriers, such as a sea wall. Accommodation strategies modify or redesign infrastructure, so it is better able to cope with expected impacts. Finally, relocation strategies reduce exposure to climate impacts by moving critical infrastructure away from areas where it is likely to be affected. An example would be relocating an evacuation route vulnerable to flooding further inland.

3.2 Specific Strategies Applicable to the Northeast Florida Region

The following section presents proven adaptation strategies selected for their applicability to the TPO's service area and the climate impacts of Sea Level Rise (SLR), storm surge and inland or riverine flooding. These strategies have been organized by their applicability for addressing coastal, riverine and stormwater-related impacts. Each strategy needs to be carefully evaluated for its suitability in addressing a specific vulnerability, as well as its cost and the level of risk-reduction it provides. Together the strategies form a toolbox of potential adaptation measures which could be selected for implementation.

3.3 Coastal Flooding Adaptation Strategies

Coastal adaptation strategies are designed to provide resilience to storm surge and SLR impacts. Since limited-access roads are generally located away from the coast, these strategies are primarily applicable to mixed-traffic routes, pedestrian facilities and bridges.

[1] FHWA Climate Adaptation Framework 3rd edition

3.3.1 - Maintain and Manage

- *Maintain existing protection systems*
    - This low-cost strategy involves maintaining existing coastal protection systems to ensure performance as designed during a storm event. While existing protection systems may be adequate for current conditions, this strategy may be ineffective in the future due to SLR or more severe storms.
- *Reroute traffic during extreme events*
    - This management strategy can be implemented at relatively low-cost to redirect traffic around impacted facilities during or after an extreme event which causes inundation or damage. Pre-planning is necessary to ensure alternate routes are identified in advance.
- *Smart Infrastructure*
    - This strategy can be medium to high-cost depending on the scale and type of technology deployed. Smart infrastructure such as connected wind speed sensors*, flood gauges, cameras, digital signage and management facilities can improve resilience to coastal flooding impacts by providing transportation managers/emergency personnel access to live information that can assist in road closures or reroute traffic around impacted facilities.

3.3.2 - Increase redundancy

- *Construct an alternative access route that is not susceptible to flooding*
    - This high-cost strategy can ensure access to critical facilities is maintained during an extreme event. It could also be used to compensate for loss of existing facilities due to SLR.

3.3.3 - Protect or Harden

- *Construct a sea wall or revetment to prevent storm surge / wave damage*
    - This high-cost strategy involves constructing a revetment/seawall along a coastal roadway to prevent wave damage associated with storm surge or SLR flooding. This strategy could have negative impacts on beach access or erosion, and is subject to failure once SLR reaches a certain threshold.
- *Construct a living shoreline to attenuate storm surge*
    - This medium-cost strategy incorporates natural vegetation or other living elements, often in combination with some type of harder shoreline structure, like oyster reefs or rock sills or for added stability. In addition to reducing erosion and stabilizing the shoreline, this strategy can provide co-benefits such as habitat restoration.

* - North Florida TPO has funded the installation of wind sensors on 19 area bridges in the region

- *Beach re-nourishment and dune construction*
  - This high-cost strategy can have co-benefits for tourism, economic development and habitat restoration. Periodic beach nourishment or sand dune construction can help prevent wave damage from storm surge.

3.3.4 - Accommodate

- *Harden bridge infrastructure to resist wave damage*
  - This medium-cost strategy involves strengthening connections or modify cross-sections on coastal bridges to prevent storm surge wave damage.
- *Raise bridge elevations*
  - This high-cost strategy involves increasing coastal bridge deck elevation above anticipated storm surge and SLR inundation levels. Due to cost, it is most suitable for incorporating in the design of new facilities. Lower spans and approach roads can still be vulnerable even if the bridge deck is raised.
- *Elevate roadway segments*
  - This high cost strategy involves elevating the most vulnerable segments of at-risk roadways above anticipated storm surge or SLR levels. Due to cost, it is typically only used for critical or high-use facilities.

3.3.5 - Relocate

- *Relocate asset to protect from storm surge / Sea Level Rise (SLR) inundation*
  - This high-cost adaptation strategy involves relocating facilities or bridges to protect them from damage or inundation due to storm surge or SLR flooding. In some cases, this may be a locally preferred or the best option available.

3.4 Riverine Flooding Adaptation Strategies

Riverine adaptation strategies provide resilience to flooding caused by extreme precipitation and storms. Riverine flooding can originate from storm events outside the North Florida region and can persist for weeks or months following an extreme event. Since limited-access roads are generally located away from the coast, they are applicable to mixed-traffic routes, pedestrian facilities and bridges.

3.4.1 - Maintain and Manage

- *Maintain existing protection systems*
  - This low-cost strategy involves maintaining existing protection systems to ensure capability of performing as designed during a riverine flooding event.
- *Reroute traffic during extreme events*
  - This management strategy can be implemented at relatively low-cost to redirect traffic around impacted facilities during or after a riverine flooding event. Pre-planning is necessary to ensure alternate routes are identified.

- *Smart Infrastructure*
    - This strategy can be medium to high-cost depending on the scale and type of technology deployed. Smart infrastructure such as connected wind speed sensors, flood gauges, cameras, digital signage and management facilities can improve resilience to riverine flooding impacts by providing transportation managers and emergency service personnel access to live information that can help them close roads or reroute traffic around impacted facilities.

3.4.2 - Increase redundancy

- *Construct an alternative access route that is not susceptible to flooding*
    - This high-cost strategy can ensure access to critical facilities is maintained during a riverine flooding event.

3.4.3 - Protect or Harden

- *Retrofit existing flood control infrastructure (e.g., dams) to provide added capacity*
    - This medium to high-cost strategy involves retrofitting existing flood control infrastructure to handle increased flows associated with riverine flooding events. Although costs are not insignificant, they may be lower than constructing new infrastructure.
- *Harden embankments*
    - This medium cost strategy involves hardening river, stream or roadway embankments using retaining walls, gabions, pavers or other means. It can prevent failure by erosion during a storm event, but increase flow velocity and require more maintenance than other options.
- *Elevate above flood conditions*
    - This high-cost strategy involves elevating roadways or bridges above projected elevations or riverine flooding. Although it is an effective way to reduce vulnerability, it is an expensive option typically used as a last resort.

3.4.4 - Accommodate

- *Watershed restoration*
    - This high-cost strategy involves planning and implementing regional drainage area management by considering the entire drainage area and determining best practices for managing drainage. It could help reduce flooding risks over a large area, but also may be costly and require a lengthy process to implement.
- *Stream restoration and floodplain enhancement*
    - This medium-cost strategy reduces risk by creating planned floodplains that can reduce flood levels in vulnerable areas. It is scalable and can be a localized treatment technique that could occur within existing rights-of-way. Long-term maintenance may be required.

3.4.5 - Relocate

- *Relocate asset to protect from storm surge / SLR inundation*
  - This high-cost adaptation strategy involves relocating facilities or bridges to protect them from damage or inundation due to riverine flooding. In some cases, this may be a locally preferred option, or the best option available.

3.5 Stormwater Strategies

Stormwater strategies address the resilience of stormwater infrastructure in areas vulnerable to both coastal and riverine flooding. They are applicable to limited access, mixed use and pedestrian facilities, and in some instances to bridges.

3.5.1 - Maintain and Manage

- *Maintain existing stormwater systems*
  - This low-cost strategy involves maintaining existing stormwater infrastructure to ensure it can handle design flows during a storm event. This may involve keeping systems clear of debris.
- Updated design standards for stormwater drainage systems
  - This low-cost management strategy involves updating design standards for stormwater drainage systems to ensure they are designed with sufficient capacity to handle future conditions.
- Mapping stormwater failures and/or historical flooding hotspots
  - This medium-cost management strategy involves mapping points of failure or trouble spots in the stormwater drainage system, especially along vulnerable or critical facilities. It can help prioritize areas needing drainage improvements to increase resilience.

3.5.2 - Increase redundancy

- *Install additional transverse and longitudinal drainage systems*
  - This medium-cost strategy involves installing additional stormwater drainage infrastructure along road segments vulnerable to nuisance or temporary flooding, to ensure drainage systems have the necessary capacity to protect critical areas.

3.5.3 - Protect or Harden

- *Stabilize slopes*
  - This medium-cost strategy involves stabilizing slopes of embankments, overpasses and bridge abutments by installing subsurface drainage, providing surface drainage or revegetating slopes with native plants. These measures can reduce water pressure and runoff flow rates and slope instability, reducing failure rates.

- *Replacing metal culverts with reinforced concrete*
  - This medium-cost measure involves replacing metal culverts that are prone to corrosion and eventual failure with reinforced concrete. Culverts can also be resized to handle increased stormwater runoff.

3.5.4 - Accommodate

- *Green Infrastructure*
  - This medium-cost strategy involves incorporating green infrastructure into designs for new or renovated stormwater systems, resulting in increased water retention capacity and slower infiltration. Green infrastructure solutions can also have additional benefits such as water quality improvements.

4 Planning-Level Cost Estimates

Acknowledging that projects will require site-specific engineered solutions, applicable strategies may range from planning and temporal interventions to protection or relocation of transportation assets. Where possible, scenarios are based on case studies of actual projects that have been designed or implemented. However, they should be taken as examples since actual costs will vary greatly due to site characteristics and other variables.

The format is as follow:

Scenario Name	***Applicable Environments (River, Storm, Coast, All)***	
Cost Estimate	***Low Range ($)***	***High Range ($)***

The following scenarios are considered for application in Northeast Florida.

1. Pre-disaster preparation	Applies to All	
Cost Estimate	*Low*	*High*
Range	Not assigned	Not assigned

Pre-disaster preparation of assets includes maintaining an inventory of equipment, facilities and systems critical to the region. Consider enhancing existing data sources that the TPO already manages (traffic data, geospatial data, databases, etc.) with appropriate resilience or vulnerability measures. No monetary value has been assigned as this does not impact infrastructure.

2. Traffic Reroute/mi	Applies to All	
Cost Estimate	*Low*	*High*
Range	$500/day	>$4,000/day

Traffic reroute cost can range depending on the complexity of the location and the duration of the event. Traffic reroute is considered a temporary solution on most cases. The range provided assumes on the low end a short disruption on a four-lane highway with minimal temporary signage and on the high end using enforcement officers, barriers and a temporary bypass bridge on a busy arterial. Solutions must also consider impacts to pedestrians, bicyclists and transit.

3. Installation of ITS/Sensor Infrastructure		Applies to All
Cost Estimate	*Low*	*High*
Range	$14,000	$3,500,000

This cost estimate is applicable to two scenarios: first, the use of ITS/sensors to aid in emergency/disaster management and second, the cost associated with replacing ITS equipment located/impacted in a vulnerable zone.

On the low end, this scenario estimates installing one simple ITS device such as CCTV and the connection to existing infrastructure to monitor the conditions within a 1-mile segment. CCTV, wind sensors, flood sensors among others can be useful tools to alert the population of impending flooding or storm surge conditions.

At the higher end, the cost of installing a gantry across an interstate segment, including design and replacing a structure and all accompanying devices (cameras, sensors, boards). A gantry system can project emergency information, host sensors and provide redundancy when needed. It is estimated that a new toll gantry structure (including communication, fans, high-tech cameras, etc.) costs around $3-3.5 million to design and install. The high-range cost estimate is applicable for tolls, expressways and interstates and not at collectors or local roads.

4. Green Infrastructure near bridges		Applies to **Coastal Flooding – Bridge Protection**
Cost Estimate	*Low*	*High*
Range	$40,000/mi	$240,000/mi

Green infrastructure (GI) can be an important solution for coastal or inland flooding that also has the potential to provide ancillary benefits. Besides improving drainage and attenuating wave action, GI can improve aesthetics, lower maintenance costs and provide wildlife habitat.

Green Infrastructure (GI) applied in a transportation context can take many forms. The GI scenario presented here is based in part on the FHWA's Henderson Point Connector (US 90): Green Infrastructure Techniques for Coastal Highway Resilience case study (2018).

The scenario includes protecting a low-elevation coastal bridge over a two-lane highway. For low-elevation bridge spans over land, extending the embankment to higher elevations can reduce vulnerability to flood events. The scenario envisions utilizing vegetated berms to redirect flood flows away from bridge abutment and approach spans, lessening the chance of failure in a storm surge event. The berms could be constructed completely within the existing right-of-way and would require little long-term maintenance. Under Option 1, the berms would be constructed of earthen fill and under Option 2, they would be reinforced with a rock core.

For both options, slopes would be stabilized with natural ground cover, native vegetation and trees.

Estimated costs for this adaptation measure range from $20,000 (Option 1) to $120,000 (Option 2) per project. Assuming roughly a 0.5-mile segment, this scenario is a relative low-cost alternative to harden certain bridges.

5. Green Infrastructure at urban streets		Applies to **Stormwater Flooding - Sustainable Streets**
Cost Estimate	*Low*	*High*
Range	$250,000 /mi	$16 million/mi

GI strategies, including low-impact development (LID), can be incorporated into city streets designs to reduce stormwater flooding due to extreme precipitation. Strategies range from rain gardens/bioretention planter boxes along urban corridors at $16.050/SF, or roughly $250,000 assuming 40 percent of coverage on both sides of the road. It should be noted that often the maintenance costs associated with green infrastructure are higher than traditional designs. However, agencies and municipalities should also consider increased costs in municipal stormwater treatment systems when considering traditional solutions.

A scenario based on the City of Chicago's Pilsen Sustainable Streetscape project involves constructing a city street that includes a variety of green infrastructure elements to increase infiltration of stormwater and reduce flooding of the roadway. These features include bioswales, rain gardens, permeable pavements and other stormwater management measures that divert up to 80 percent of the typical average annual rainfall away from the combined sewer system. High albedo (reflection) pavement surfaces reduce urban heat island effects and drought tolerant, native vegetation increases landscape and tree canopy cover to shade the right of way and provide additional stormwater filtration. Estimated costs for this adaptation measure are $7 million per mile. In St. Augustine, FDOT is currently planning to improve drainage on a half-mile segment of Kings Street, including new pipes and other drainage infrastructure, new sidewalks and new pavement for the existing two-lane with center lane street at a cost of $8.4 million.

6. Protect Roadway: Seawall along road		Applies to **Coastal Flooding**
Cost Estimate	*Low*	*High*
Range	$4 Million/mi	$36 Million/mi

Seawall costs will vary by location, solution and the relative height of the wall. Often bulkheads need to be installed or replaced at short segments which makes the cost per mile on the high-range more consistent with smaller projects due to economies of scale. Using engineering estimates from previous projects, the high range represents the probable cost of 1 mile of seawall/bulkhead in the St. Johns River near downtown. The low cost is based on a simpler vinyl bulkhead with toe protection per estimates provided to Little St. Simons Island.

7. Protect Roadway: Increase culvert capacity	Applies to **Stormwater**	
Cost Estimate	*Low*	*High*
Range	$17 Million/mi	$37 Million/mi

This scenario looks at costs associated with upgrading existing culverts over coastal creeks to handle increased flows from rainfalls that exceed design parameters for existing infrastructure. The scenario is based on FHWA's case study for upgrading the Airport Boulevard Culvert over Montlimar Creek in Mobile, Alabama.[2] It is based on a culvert which drains a 3 square mile area and which serves a 6-lane road bordered by two 2-lane service roads.

The scenario considers two options:

1. Add one culvert cell to each side of an existing crossing.
2. Replace the existing crossing with a larger crossing.

Option 1 consists of adding one additional 12 foot span by eight foot rise box culvert on each side of the existing four cells of the same size. It includes removing the existing wing walls on both sides (to stay within the right-of-way and minimize channel alignment changes), excavating and installing one box culvert on each side of the existing crossing, new headwall extensions, new training walls, and utility relocation.

Option 2 consists of removing the existing crossing and installing four cells, each with a 21-foot span by nine foot rise. The new culvert would be elevated one foot above the previous height and would include concrete training walls to accommodate a wider entrance and exit. It would include removing existing culvert and wing walls.

- Excavating and installing a culvert with four 21 foot by nine foot cells
- New headwall extensions
- New training walls
- Utility relocation

Estimated costs for this adaptation measure range from $1.7 million (Option 1) to $2.5 million (Option 2) per project. Project length is estimated at 500 ft. Values are reported for a hypothetical 1-mile segment.

5 CONCLUSIONS

The North Florida region is characterized by a multimodal, multi-asset network that can be subject to coastal flooding, riverine flooding and stormwater issues. As different transportation

[2] Impacts of Climate Change and Variability on Transportation Systems and Infrastructure, The Gulf Coast Study, Phase 2, Task 3.2, FHWA

elements may require different resiliency strategies, this toolbox evaluated resiliency best practices for the following assets:

- Interstates & Freeways – All highway segments part of the Interstate System and uninterrupted flow facilities such as Freeways and Expressways.
- Arterials – All other principal arterials and minor arterials.
- Urban local and collector roads
- Rural local and collector roads
- ITS/ Smart Region Systems – The critical technology and applications, including data, used to operate the infrastructure and enable reliable network communication.

Adaptation strategies for transportation infrastructure typically seek to increase resilience and address vulnerabilities by:

A. Managing and maintaining existing assets
B. Increasing redundancy in the network
C. Protecting and/or hardening existing assets/roads
D. Accommodating designs for flood management
E. Relocating assets

As the region continues to identify vulnerable areas, as well as existing and future stressors, the following considerations should be taken:

- The role of pre-planification and responsible stakeholders.
- The state of all assets and status of vulnerable locations.
- The type of environmental stressor (climate events) including type of flooding or storm surge.
- Current mitigation/resilience efforts by the state, counties and cities.
- Design considerations of programmed projects.
- Appropriate adaptation strategies based on cost, frequency of occurrence and probability of future events.
- Maintenance costs of green infrastructure.
- Multimodal solutions that benefit all users including pedestrian, bicycle and transit.

Given the specifics of each case study, the planning-level cost estimates show a wide range of values. As high range values are often associated with the cost of rebuilding/resurfacing a road, coordination is imperative in order to adapt or harden locations in conjunction with other public works projects (utilities, sewage, sidewalks, pavement, etc.). In areas subject to stormwater flooding, urban solutions should incorporate green infrastructure and landscape solutions in order to divert runoff from storm sewers and tributaries. In areas subject to coastal flooding, additional seawalls may need to be installed or bulkhead caps re-engineered for higher tides. Lastly, special consideration should be made to ITS as both a **solution** and an **asset** to protect.

References:

California Adaptation Planning Guide: Planning for Adaptive Communities.
Accessed June 17. 2019 at:
http://resources.ca.gov/docs/climate/01APG_Planning_for_Adaptive_Communities.pdf.

Vulnerability Assessment and Adaptation Framework, 3rd Edition, Federal Highway Administration Office of Planning, Environment, & Realty, 2017. Accessed June 17, 2019 at: https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/

Florida Adaptation Planning Guidebook. FDEP, 2018

King Street drainage to get help in St. Augustine, The St. Augustine Record - June, 10, 2019.

Henderson Point Connector (US HWY 90) Green Infrastructure Techniques for Coastal Resilience, US Dept. of Transportation & Mississippi Dept. of Transportation, 2018.

Barrier Island Roadway Overwashing from Sea Level Rise and Storm Surge: US 98 on Okaloosa Island, Florida. Federal Highway Administration, 2014. Accessed June 17, 2019 at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/fl_us_98/index.cfm

Water Environment Research Federation. Low Impact Development Best Management Practices Whole Life Cost Model 2007 for Rain Garden (Professional). Accessed June 17, 2019 at: http://greenvalues.cnt.org/national/cost_detail.php

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure, The Gulf Coast Study, Phase 2, Task 3.2, FHWA. Accessed June 17, 2019 at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/gulf_coast_study/phase2_task3/task_3.2/page04.cfm#Toc395171917

Pilsen Sustainable Streets (Chicago Illinois Dept. of Transportation), Adaptation Clearinghouse, 2012. Accessed June 17, 2019 at: https://www.adaptationclearinghouse.org/resources/pilsen-sustainable-streets-chicago-illinois-department-of-transporation.html

Hillsborough County MPO: Vulnerability Assessment and Adaptation Pilot Project, Cambridge Systematics, 2014. Accessed June 17, 2019 at: http://www.planhillsborough.org/wp-content/uploads/2013/10/NoAppendix_Hillsborough-MPO_FHWA-Pilot-Final-Report1.pdf